AD-A083 003 OHIO STATE UNIV COLUMBUS ELECTROSCIENCE LAB F/G 9/5
AN APERTURE-MATCHED HORN DESIGN.(U)
JAN 80 W D BURNSIDE, C W CHUANG N00014-78-C-0049
UNCLASSIFIED ESL-710816-5 NL

1 OF 1
AD A083003

END
DATE FILMED
5-80
DTIC

LEVEL II

14

SC

OSU

The Ohio State University

AN APERTURE-MATCHED HORN DESIGN

W.D. Burnside and C.W. Chuang

ADA083003

The Ohio State University

ElectroScience Laboratory

Department of Electrical Engineering
Columbus, Ohio 43212

TECHNICAL REPORT 710816-5

Contract N00014-78-C-0049

January 1980

Dept. of the Navy
Office of Naval Research
800 Quincy Street
Arlington, Virginia 22217

NOTICES

When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely related Government procurement operation, the United States Government thereby incurs no responsibility nor any obligation whatsoever, and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) 6 AN APERTURE-MATCHED HORN DESIGN.		5. TYPE OF REPORT & PERIOD COVERED 7 Technical Report.
		6. PERFORMING ORG. REPORT NUMBER 14 ESL-710816-5
7. AUTHOR(s) 10 W.D. Burnside, C.W. Chuang		8. CONTRACT OR GRANT NUMBER(s) Contract N00014-78-C-0049
9. PERFORMING ORGANIZATION NAME AND ADDRESS The Ohio State University ElectroScience Laboratory, Department of Electrical Engineering, Columbus, Ohio 43212		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS Project NR 371-021/9-5-78 (427)
11. CONTROLLING OFFICE NAME AND ADDRESS Dept. of the Navy, Office of Naval Research, 800 Quincy Street Arlington, Virginia 22217		12. REPORT DATE 11 Janu[redacted]980
		13. NUMBER OF PAGES 39 12 36
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved ... release;

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Electromagnetic Radiation	Improved Frequency Characteristics
Horn Design	Aperture Match Concept
Improved Pattern	Analytic Solutions
Improved Impedance	Measured Results

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A novel horn design is presented in this report which provides significantly better performance in terms of the pattern, impedance and frequency characteristics than normally obtainable. The modification necessary to accomplish these improvements is achieved with a moderate increase in the size and weight; yet, the overall cost of design and construction need not significantly increase. The basic concept utilizes an ordinary horn except that curved surface sections

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

402251

20.

are attached to the outside of the aperture edges. Although all of the original studies associated with this new antenna were made using elliptic cylinder sections, they can be arbitrary smooth convex shapes which are attached to the horn such that the junction forms a smooth surface to the touch.

ACKNOWLEDGMENTS

The authors wish to take this opportunity to thank Professor Leon Peters, Jr. and Professor Roger C. Rudduck for their assistance in developing this horn and reviewing the associated manuscript.

TABLE OF CONTENTS

I. INTRODUCTION

Horns were among the original antennas used when electromagnetic radiating systems ventured into the microwave region. One needs only to refer to the recent IEEE monograph edited by Love[1] to realize that horns remain of great practical value and interest. The earliest horns were developed by flaring the waveguide walls using planar surfaces. The so-called optimum gain horn as introduced by Schelkunoff[2] is basically such a horn whose dimensions are optimized for maximum on-axis gain. This is accomplished by adjusting the horn length and/or flare angle until the diffractions from the aperture edges add in phase with the direct radiation associated with the horn throat. Note that the optimum gain horn will normally be used here for comparison purposes in that most standard gain horns are of this type. However, the term, conventional horn, will refer to a given horn without the aperture match modification.

The E-plane pattern associated with an optimum gain horn typically has high side and back lobes which can be directly attributed to the large edge-diffracted fields. In order to improve this situation, dual-mode[3] and corrugated[4] horns are designed to greatly reduce the fields incident on the aperture edges and consequently the associated diffractions. Using the dual-mode horn philosophy, a discontinuity is introduced at a position within the horn where two modes can exist; then, the horn lengths are adjusted such that the total field (i.e. the superposition of the two modes) at the aperture edges is very small compared to the maximum aperture field magnitude. Obviously, the frequency bandwidth of such a design is decreased as compared to an optimum gain horn. Nevertheless, one can achieve improved pattern performance over about a ten percent frequency band using a carefully designed dual-mode horn.

Corrugated horns provide a means to reduce the edge diffracted fields over a broader frequency band by using specially designed corrugated surfaces on the interior horn walls which force the energy off the surface. With a sufficiently long corrugated horn, one can expect improved pattern performance over nearly a 2:1 bandwidth[4]. In that the corrugated surfaces force the energy away from the horn walls in the E-plane and the boundary conditions accomplish the same thing in the H-plane, it is not surprising that the principal plane patterns are almost identical. As a result, a corrugated horn makes an excellent circularly polarized radiator with superior axial ratio characteristics. On the other hand, the introduction of the corrugations creates additional reflections which tend to modify the horn impedance. With a proper design as described in Ref. [4], one can cause these reflections to cancel the mismatch at the throat and obtain a VSWR of less than 1.2 over a 1.7:1 frequency band. Given that an application can afford the complexities of such a design and construction, the corrugated horn can provide significantly better pattern performance than a conventional horn over a broad frequency band.

A novel horn design is introduced in this paper as shown in Fig. 1 which eliminates the troublesome edge diffractions <u>not</u> by reducing the incident field on the aperture edges but by reducing the aperture diffraction itself. This is accomplished by adding aperture curved surfaces which form smooth matching sections between the horn modes and free space radiation. With this in mind, this new horn type has been designated an "aperture-matched" horn.

II. PATTERN PERFORMANCE

Although the modification suggested here can be applied to a wide variety of horns, it is illustrative to consider a conventional pyramidal horn such as shown in Fig. 2. Considering typical principal plane patterns of such a horn as depicted in Fig. 3, the H-plane

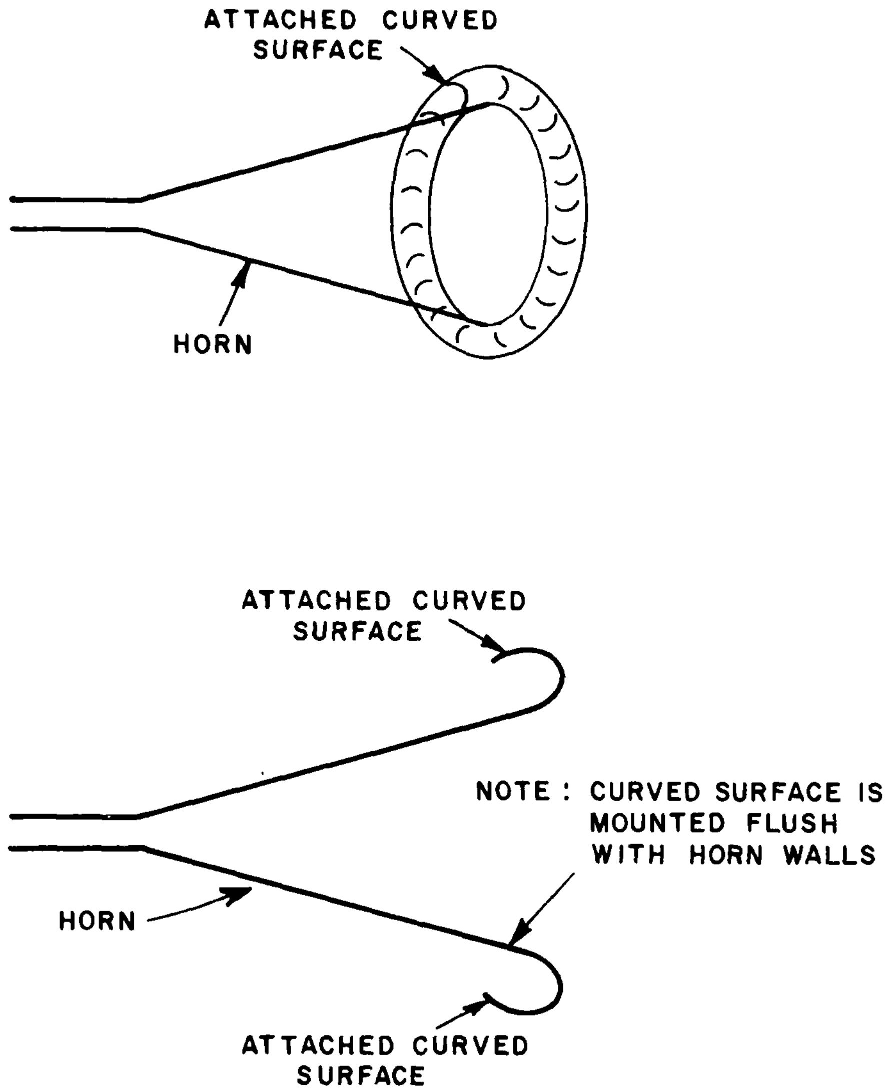


Fig. 1. Aperture matched horn.

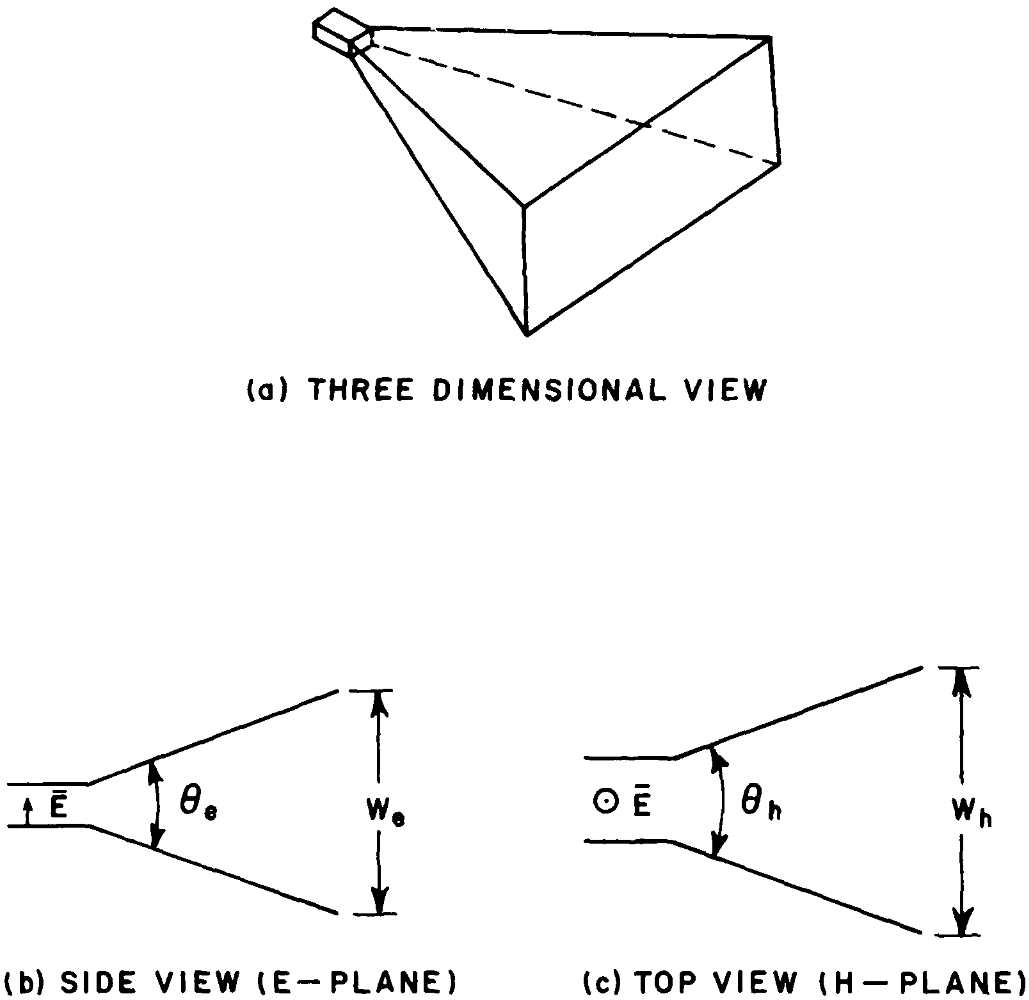


Fig. 2. Pyramidal horn geometry.

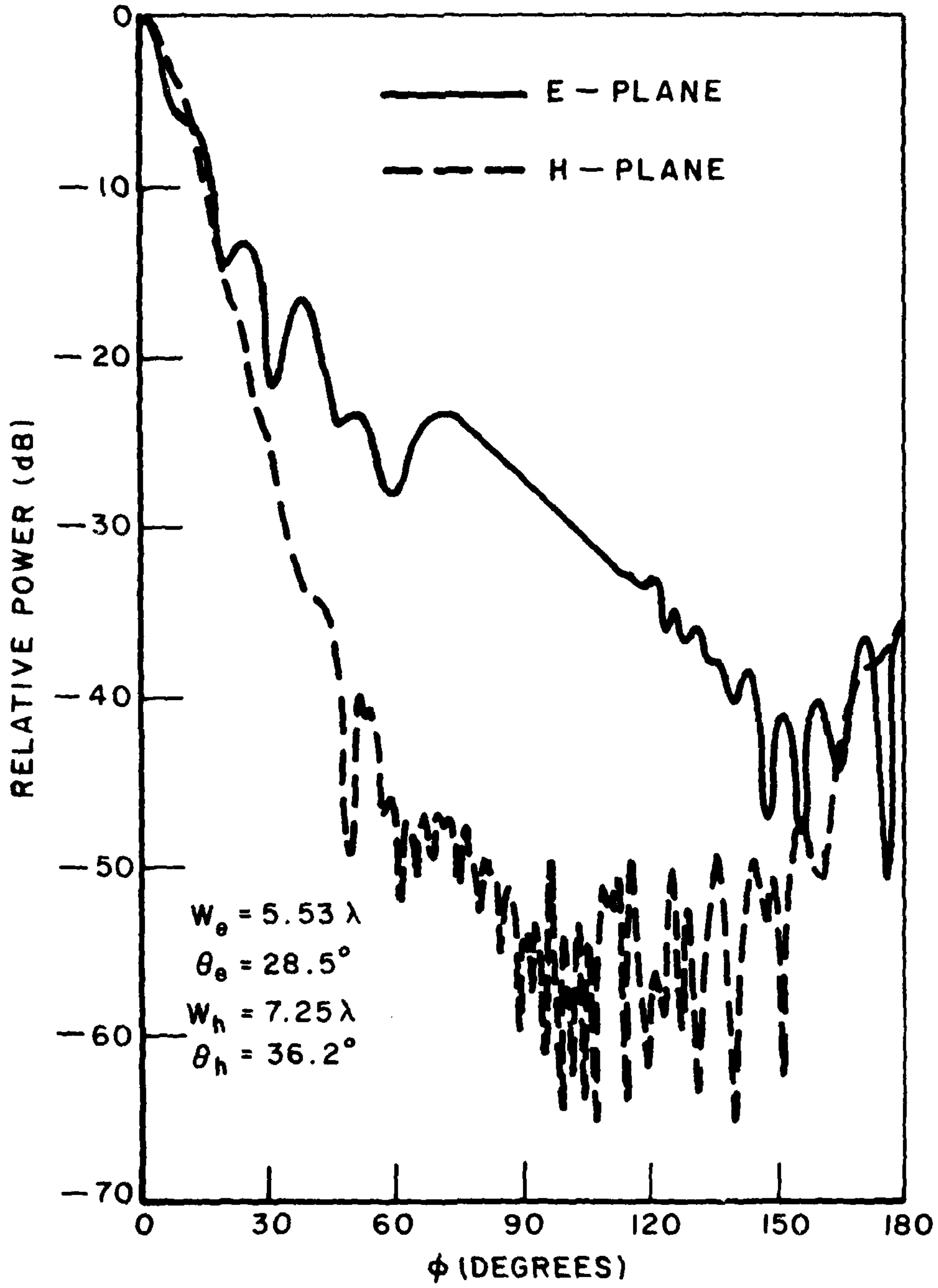


Fig. 3. Measured conventional horn patterns.

pattern is far superior to the E-plane pattern (i.e., much smoother and lower side lobes). This occurs in that the boundary conditions force a null field to be incident upon the edges creating the H-plane pattern which greatly reduces the associated diffractions. As discussed in the previous section, modern horn designs have attempted to create a null field incident on the edges creating the E-plane pattern.

In order to examine the E-plane pattern of a pyramidal horn in detail, let us consider the geometrical theory of diffraction (GTD) analysis suggested by Russo, et. al.[5]. Using this approach the pattern is dominated by three terms (i.e. direct throat radiation plus two edge diffraction terms) as illustrated in Fig. 4. In that the throat region appears as an electrically small radiator, its pattern is, as expected, smooth across the horn flare angle and zero otherwise. On the other hand, the aperture edge diffractions are widely separated from the throat and each other such that one should expect a rapid interference pattern especially if the edge diffractions are of significant magnitude as in the conventional E-plane horn pattern case. The basic first-order diffraction equation which describes this situation is given by [6]

$$\vec{E}^{d} = \vec{E}^{i} \cdot \vec{D}(d,s,\gamma)\ A(d,s)\ e^{-jks} \qquad (1)$$

where $\vec{E}^{i}$ is the field incident on the edge, $\vec{D}(d,s,\gamma)$ is the diffraction coefficient associated with the appropriate geometry, and A(d,s) is the diffracted field spread factor. Note that d is the distance from the source to the diffraction point, s is the distance from the diffraction point to the receiver, and γ represents the various angular dimensions associated with the given geometry. With Eq. (1) in mind, it is clear that one has two options if he wishes to reduce the diffracted field:

1. Reduce the magnitude of the field incident on the edge.

2. Modify the structure in order to reduce the magnitude of the diffraction coefficient and/or spread factor.

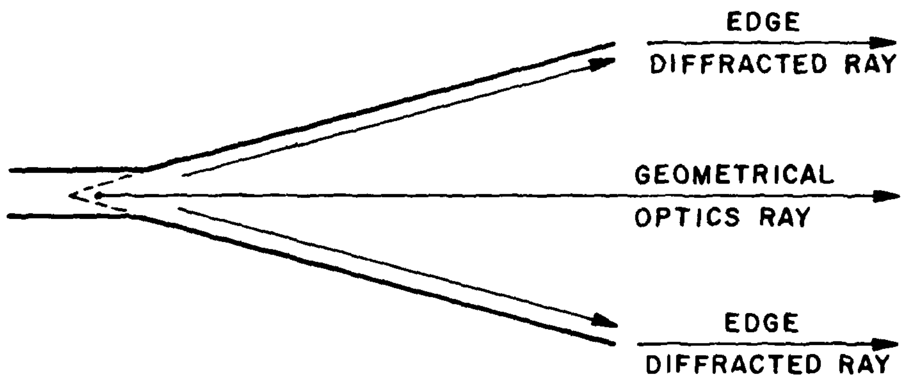


Fig. 4. GTD terms for horn E-plane pattern calculation.

As stated earlier, the dual-mode and corrugated horns achieve improved pattern performance by using the first option. However, it appears that such horn designs are trading off one virtue for another, i.e. the dual-mode horn is more frequency sensitive, and the corrugated horn is more complex and costly. In order to obtain a horn with improved pattern and impedance performance without greatly sacrificing the size, weight, bandwidth and cost, let us consider the second option (i.e. reduce the magnitude of the diffraction coefficient). This can be done by modifying the horn as illustrated in Fig. 1 by attaching curved surface sections to the aperture edges so that the resulting junction is smooth to the touch. These curved surface sections can be arbitrary smooth convex shapes; additionally, the cross-sectional shape can vary along the length of the edge. However, the following discussions are based on elliptic cylinder sections in that they can be theoretically analyzed.

Before applying this modification to a conventional horn, it is informative to consider the basic structure shown in Fig. 5, which consists of a magnetic line source mounted on a planar surface that is terminated by an elliptic cylinder. The diffraction coefficient associated with this structure is numerically analyzed using the method suggested by Chuang and Burnside[7]. Some examples of this study are shown in Figs. 6-12 where the various parameters are defined in Fig. 5. In Fig. 6, the magnitude of the diffraction coefficient ($|D|/\sqrt{d}$ in Eq. (1)) is plotted as a function of angle for various circular cylinder radii. It is apparent from these results that the diffracted field from the terminated surface is reduced as the cylinder radius is increased. For a given semi-minor elliptic dimension (a), the diffraction coefficient magnitude is reduced, especially in the lit region ($-90^{\circ} < \phi < 90^{\circ}$), as the semi-major dimension (b) is increased as shown in Fig. 7. As shown in Fig. 8, the magnitude of the diffraction coefficient is reduced more for the terminated surface if the magnetic line source is located away from the junction. In order to

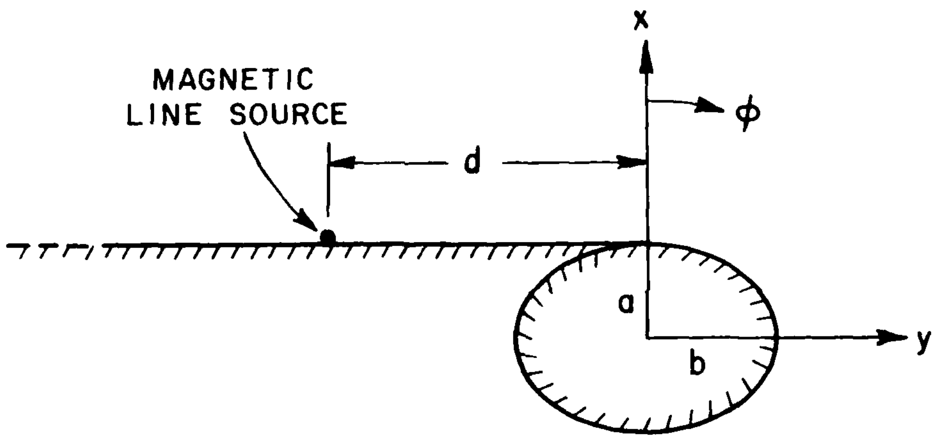


Fig. 5. Magnetic line source mounted on a ground plane terminated by an elliptic cylinder.

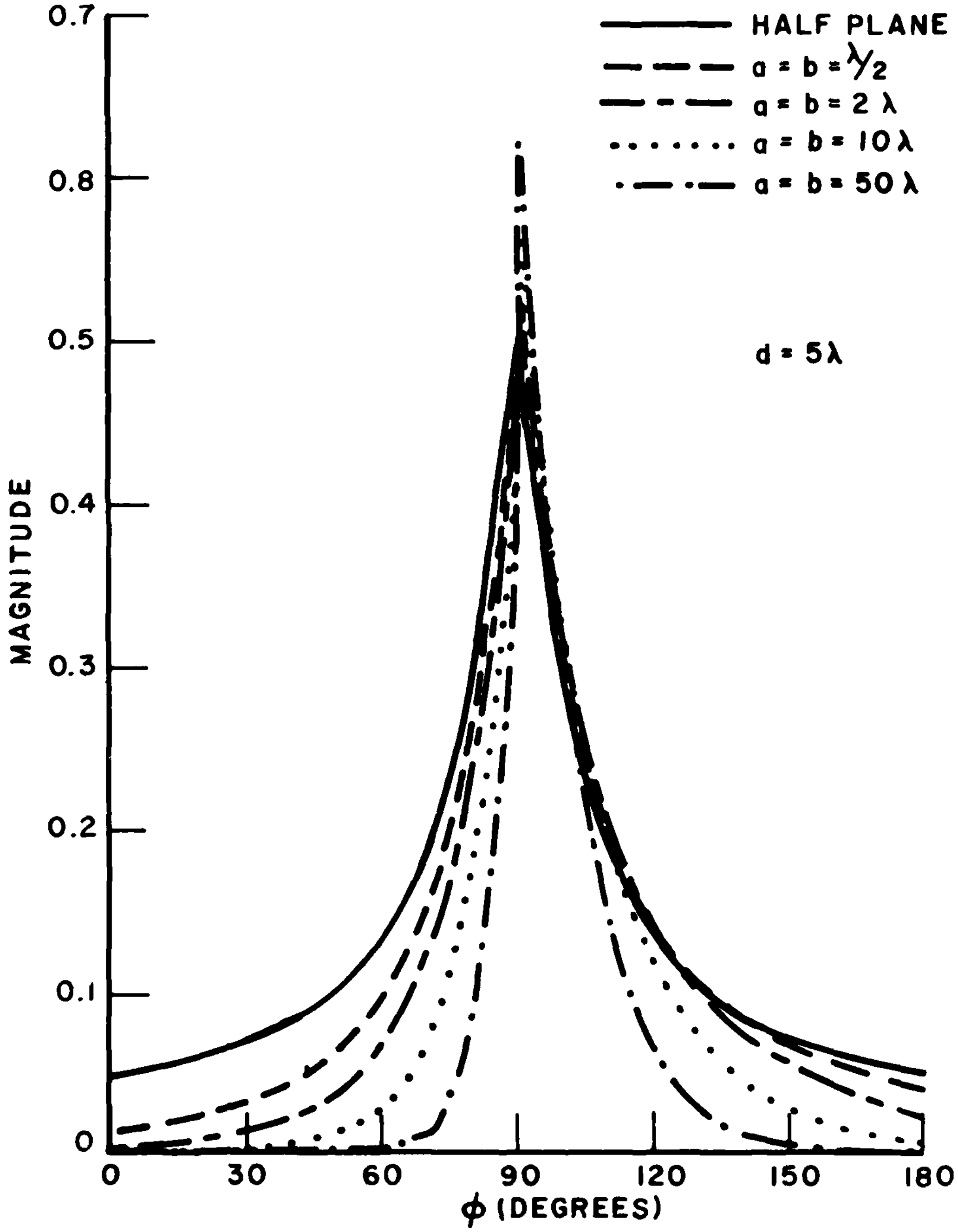


Fig. 6. Magnitude of diffraction coefficient $(D(d,s)/\sqrt{d})$ for various circular cylinder radii.

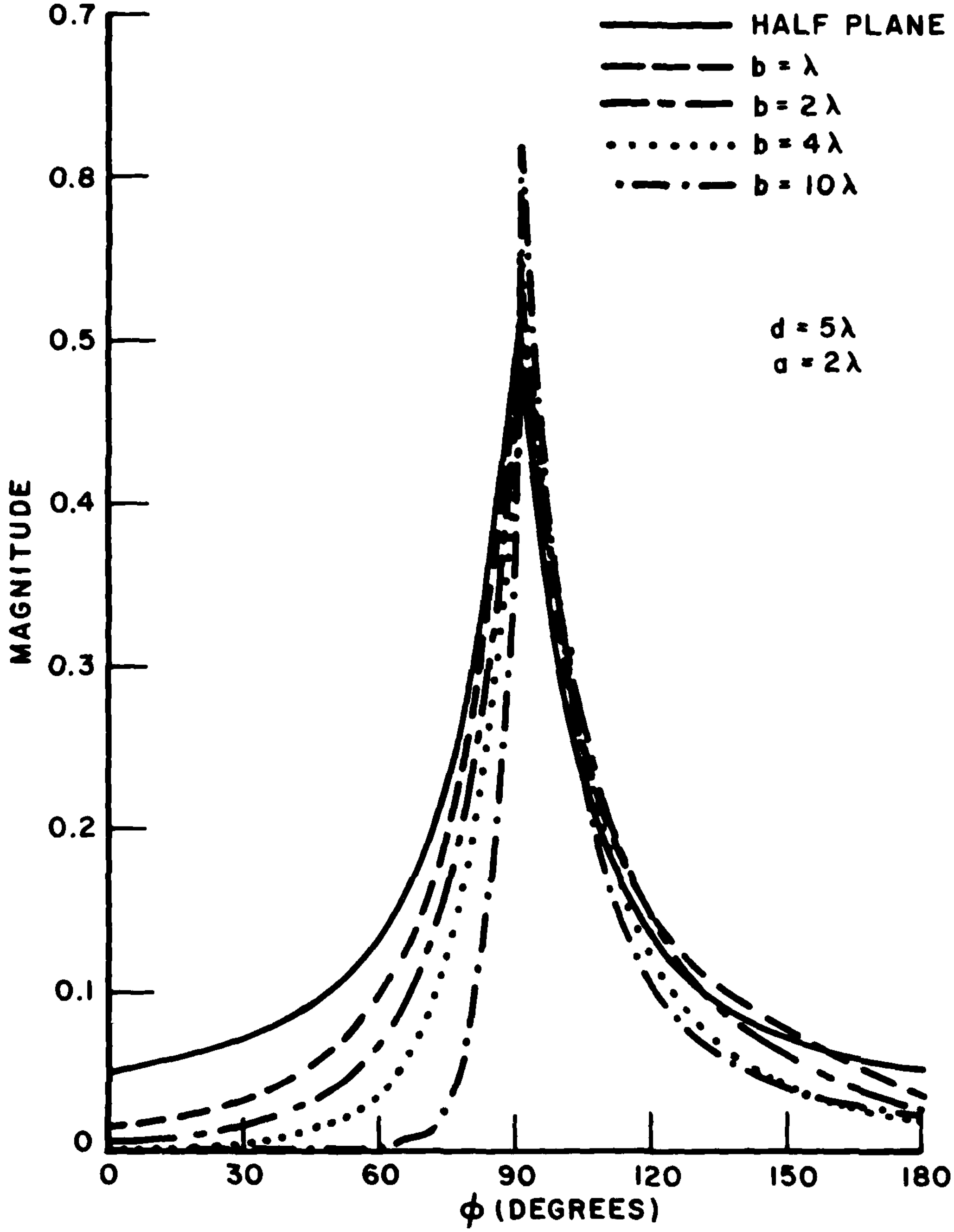


Fig. 7. Magnitude of diffraction coefficient ($D(d,s)/\sqrt{d}$) for various elliptic cylinder terminations.

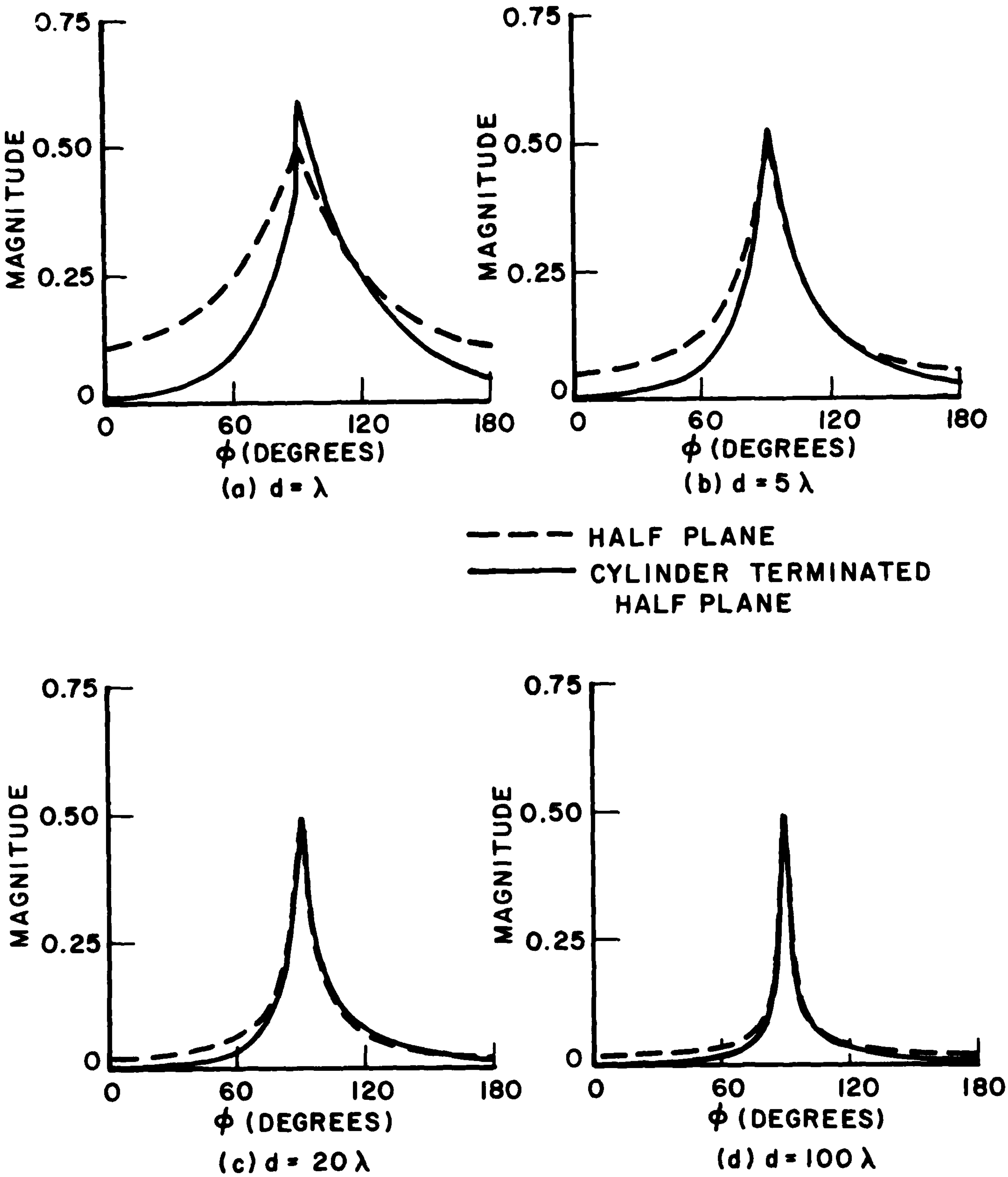
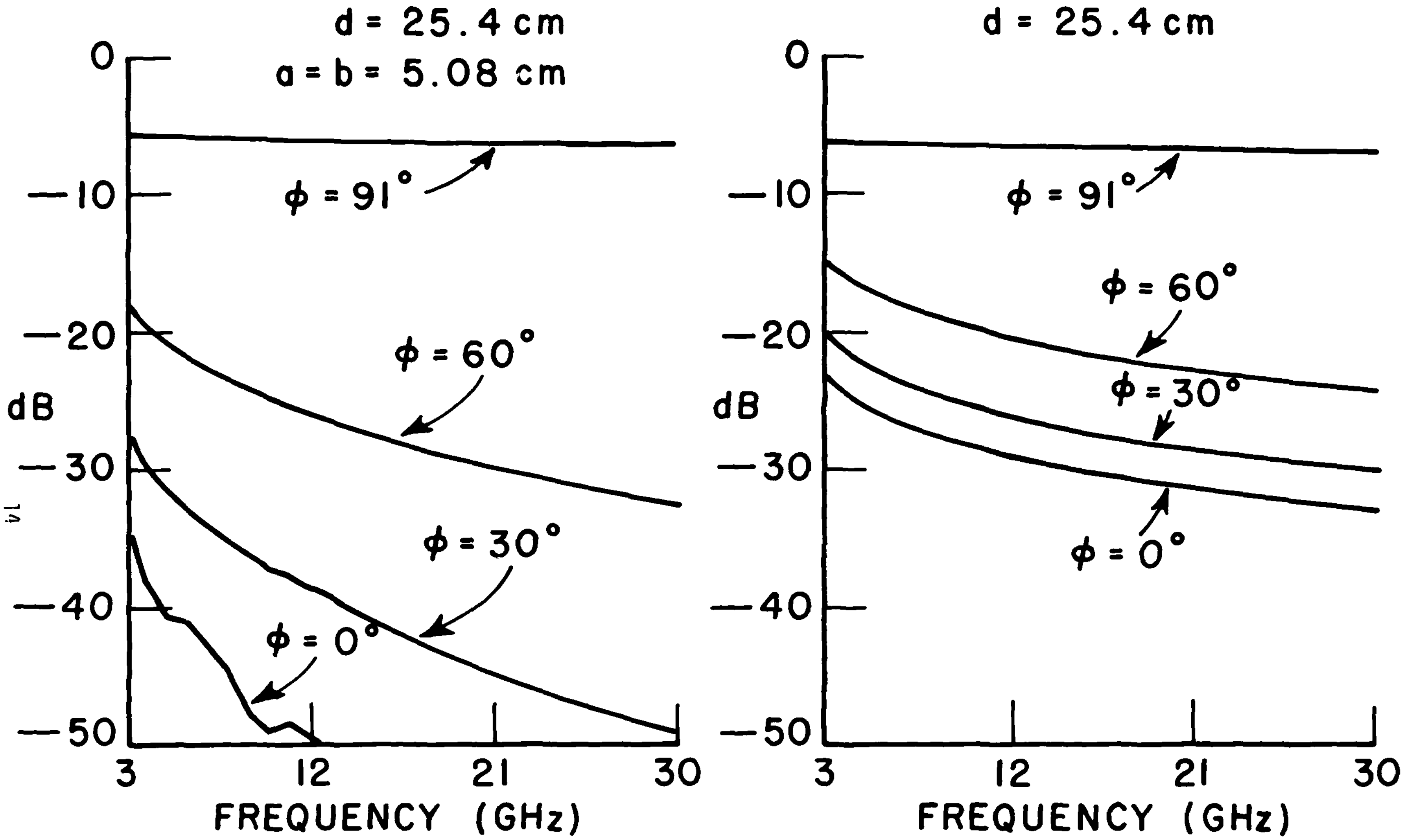


Fig. 8. Magnitude of diffraction coefficient $(D(d,s)/\sqrt{d})$ for various magnetic line source positions.

compare the reduction in the diffraction coefficient magnitude as a function of frequency, it is shown in Figs. 9 and 10 for various diffraction angles. Note that the reduction is much greater in the lit region ($-90^o<\phi<90^o$) than the shadow region ($90^o<\phi<270^o$). The diffraction coefficient magnitude over a broad frequency band for the terminated surface is shown in Figs. 11 and 12 for various source positions, cylinder radii and diffraction angles. It is interesting to note that even a small radius cylindrical section provides a great improvement in the lit region; whereas, a large radius is needed to significantly reduce the magnitude of the diffracted field in the shadow region.

Based on the reduction of the diffraction coefficient magnitude, it appears appropriate to demonstrate the improvement obtained by adding this modification to a conventional horn. Recall that Russo, et. al.[5] used the edge diffraction solution to obtain the E-plane pattern of a conventional horn, the same mechanisms are appropriate to analyze the "aperture-matched" horn if the planar/curved surface diffraction coefficients are substituted for the edge terms. Using the three GTD terms illustrated in Fig. 13, some calculated and measured E-plane horn patterns are shown in Figs. 14 and 15. Note that even though the background reflection level of our anechoic chamber exceeded that of the "aperture-matched" horn back lobe as illustrated in Fig. 14b, its patterns are much smoother and the back lobe is greatly reduced compared to a conventional horn. Actually this curved surface modification provides this improvement by forming an aperture match between the horn modes and free space such that the energy flows essentially undisturbed across the junction, around the curved surfaces, and into space. As a consequence, the aperture reflections back into the horn are negligibly small for this geometry as will be discussed later.

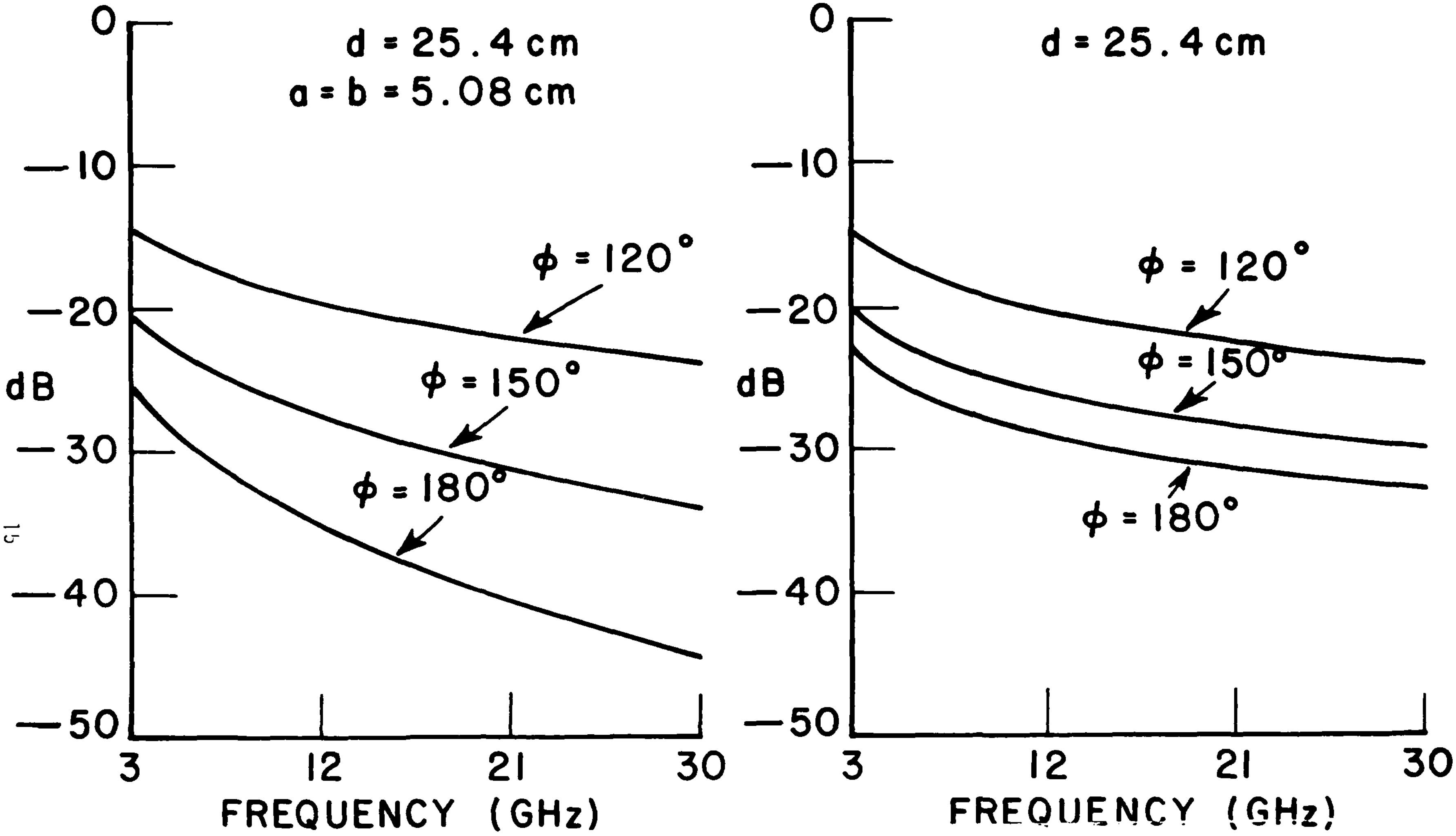
In that E-plane pattern illustrated in Fig. 15 is reminiscent of that obtained using a corrugated horn, it is interesting to compare the "aperture-matched" and corrugated horns assuming that they



(a) Curved Surface Terminated

(b) Half Plane

Fig. 9. Magnitude of diffraction coefficient $(D(d,s)/\sqrt{d})$ for various diffraction angles over a broad frequency range.



(a) Curved Surface Terminated

(b) Half Plane

Fig. 10. Magnitude of diffraction coefficient $(D(d,s)/\sqrt{d})$ for various diffraction angles over a broad frequency range.

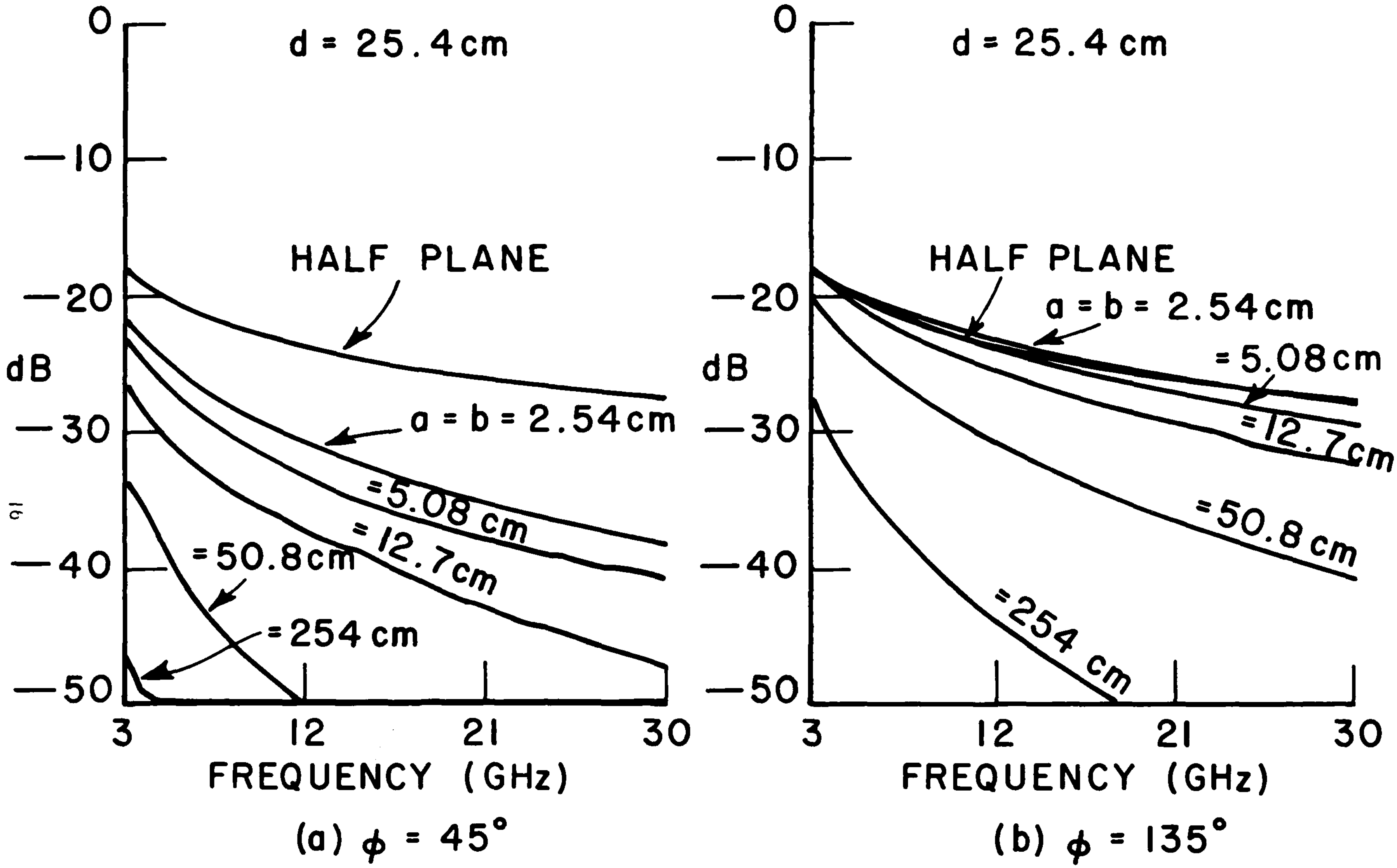


Fig. 11. Magnitude of diffraction coefficient $(D(d,s)/\sqrt{d})$ for various circular cylinder terminations over a broad frequency range.

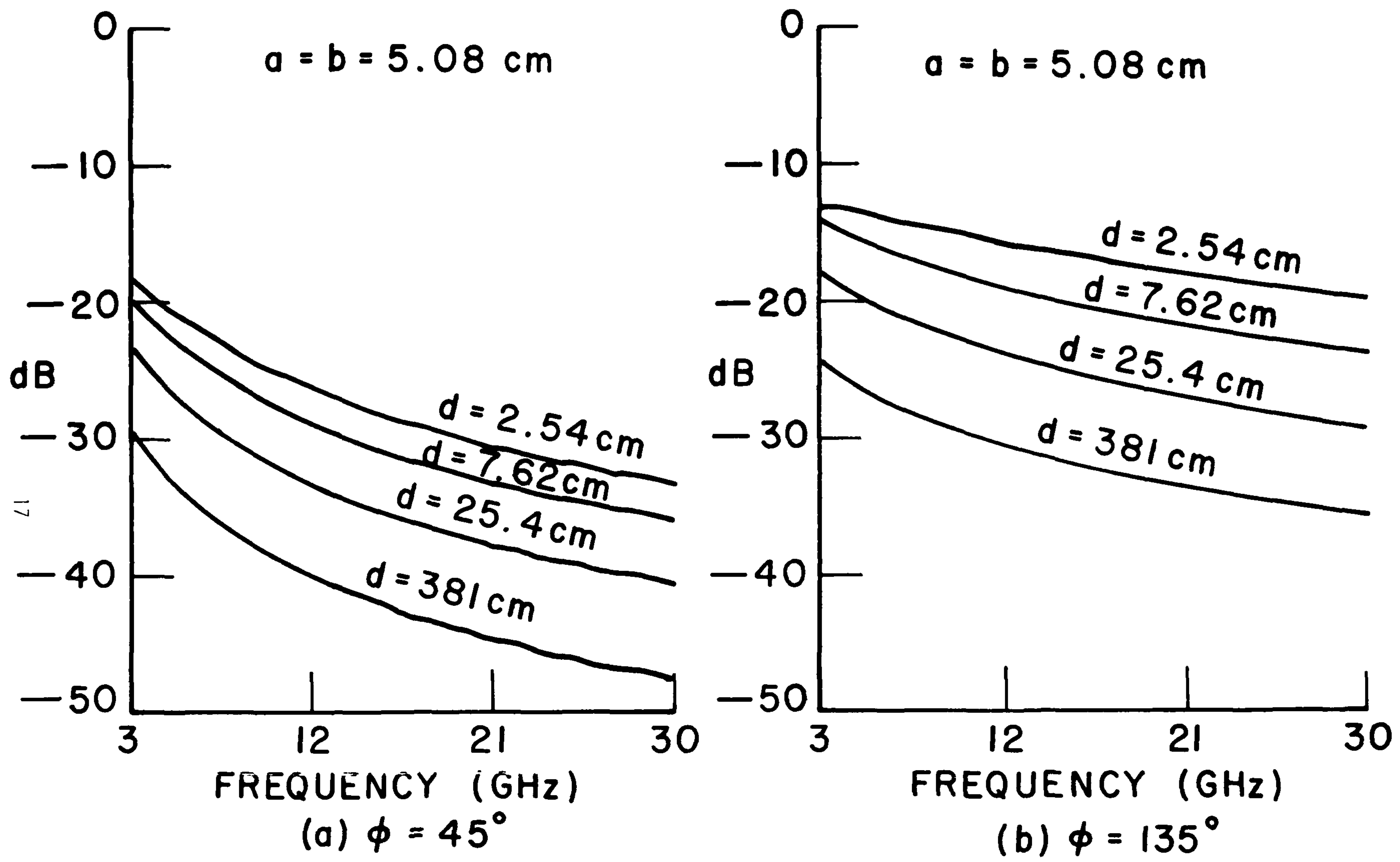


Fig. 12. Magnitude of diffraction coefficient $(D(d,s)/\sqrt{d})$ for various magnetic line source positions over a broad frequency range.

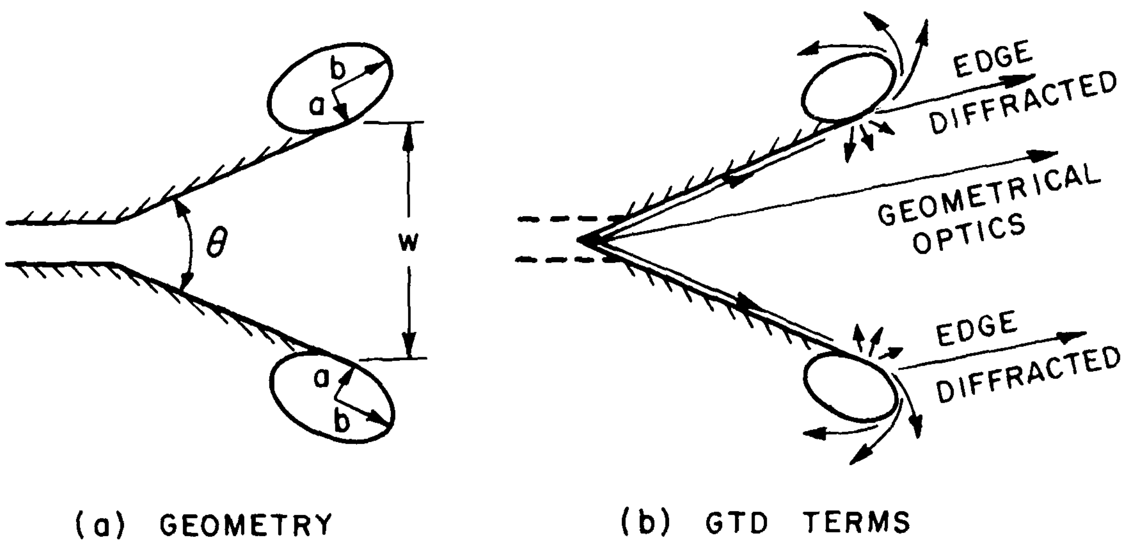


Fig. 13. "Aperture-matched" horn geometry and GTD pattern analysis model.

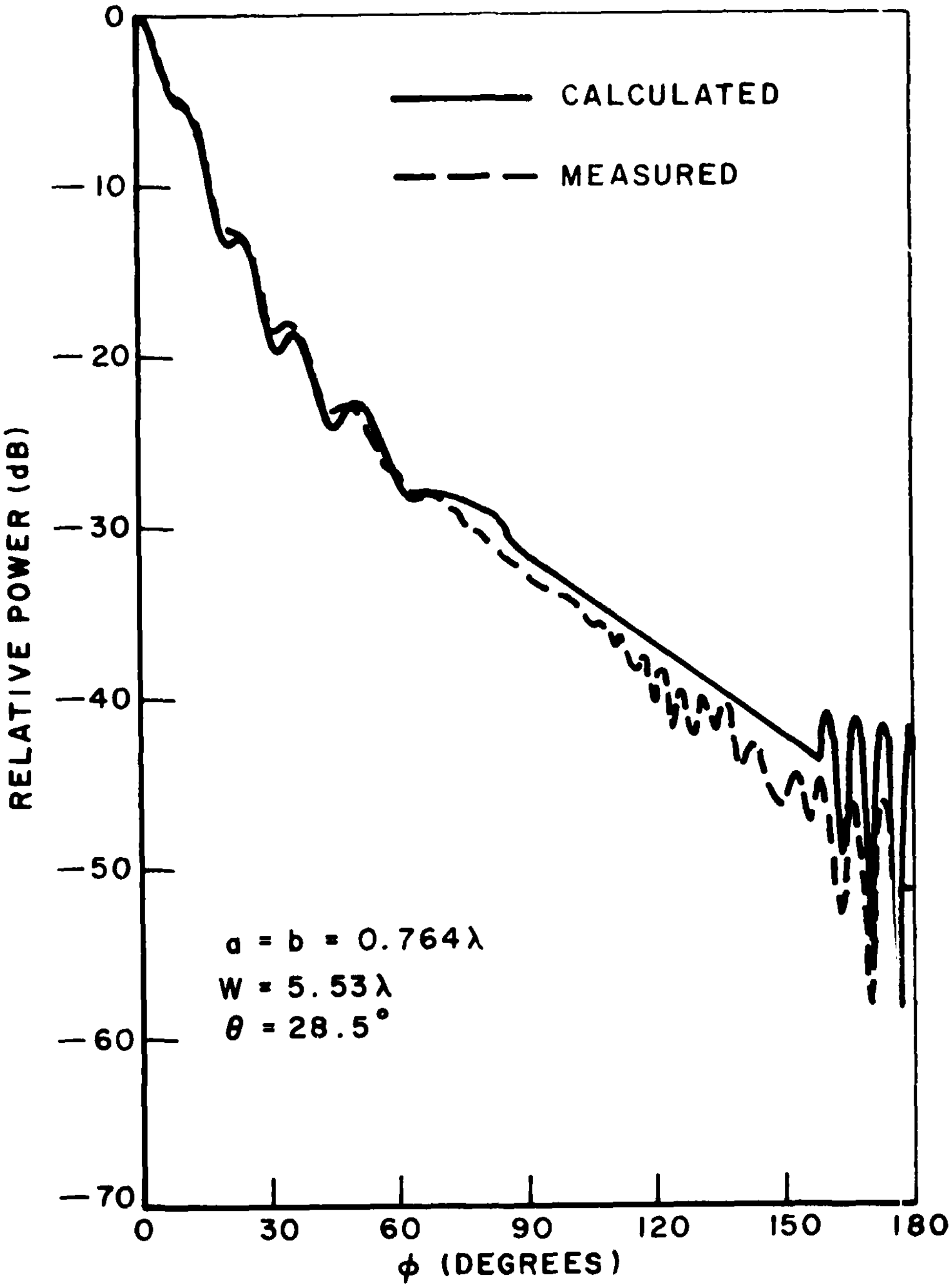


Fig. 14a. E-plane pattern of "aperture-matched" horn.

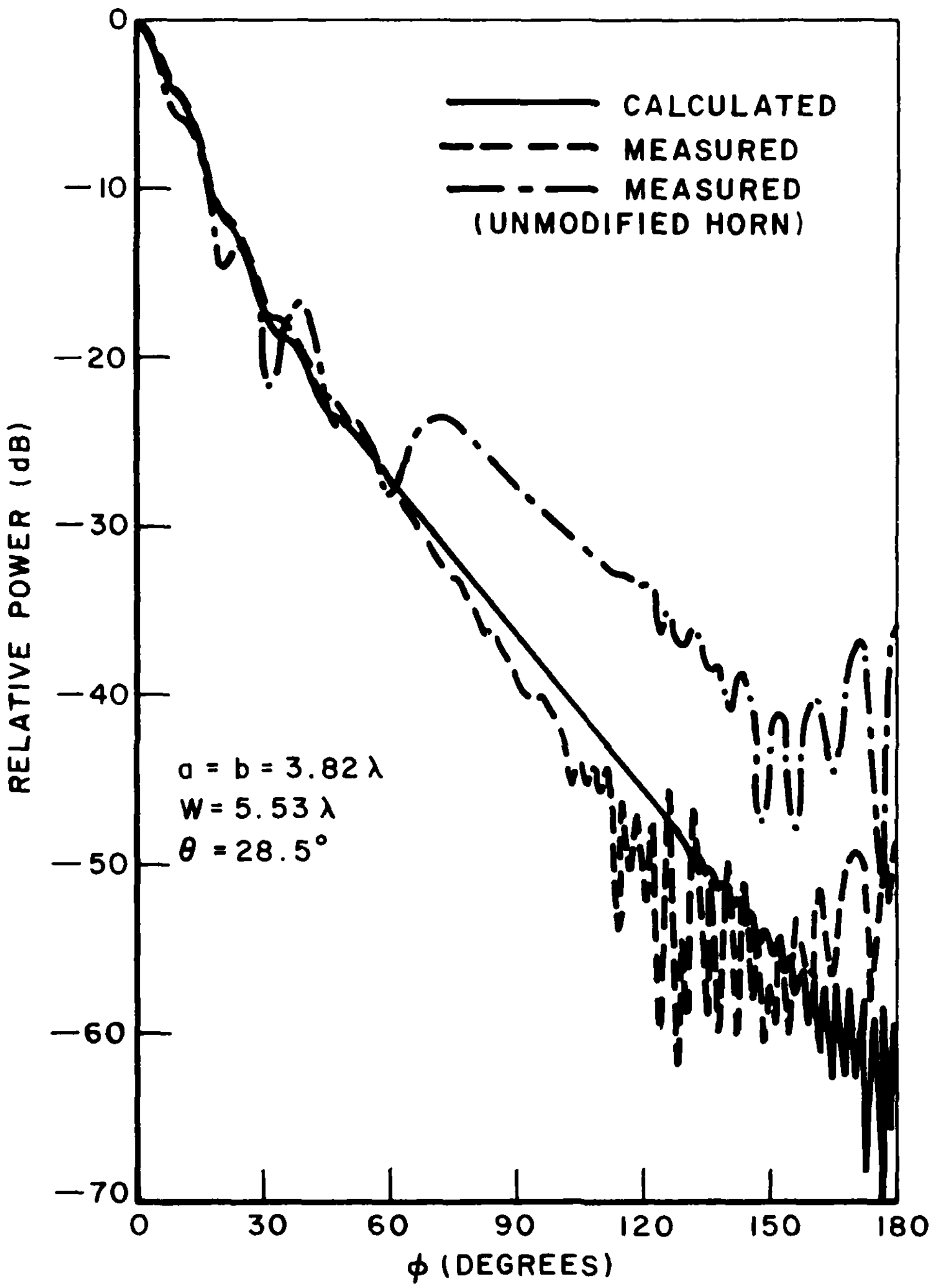


Fig. 14b. E-plane pattern of "aperture-matched" horn.

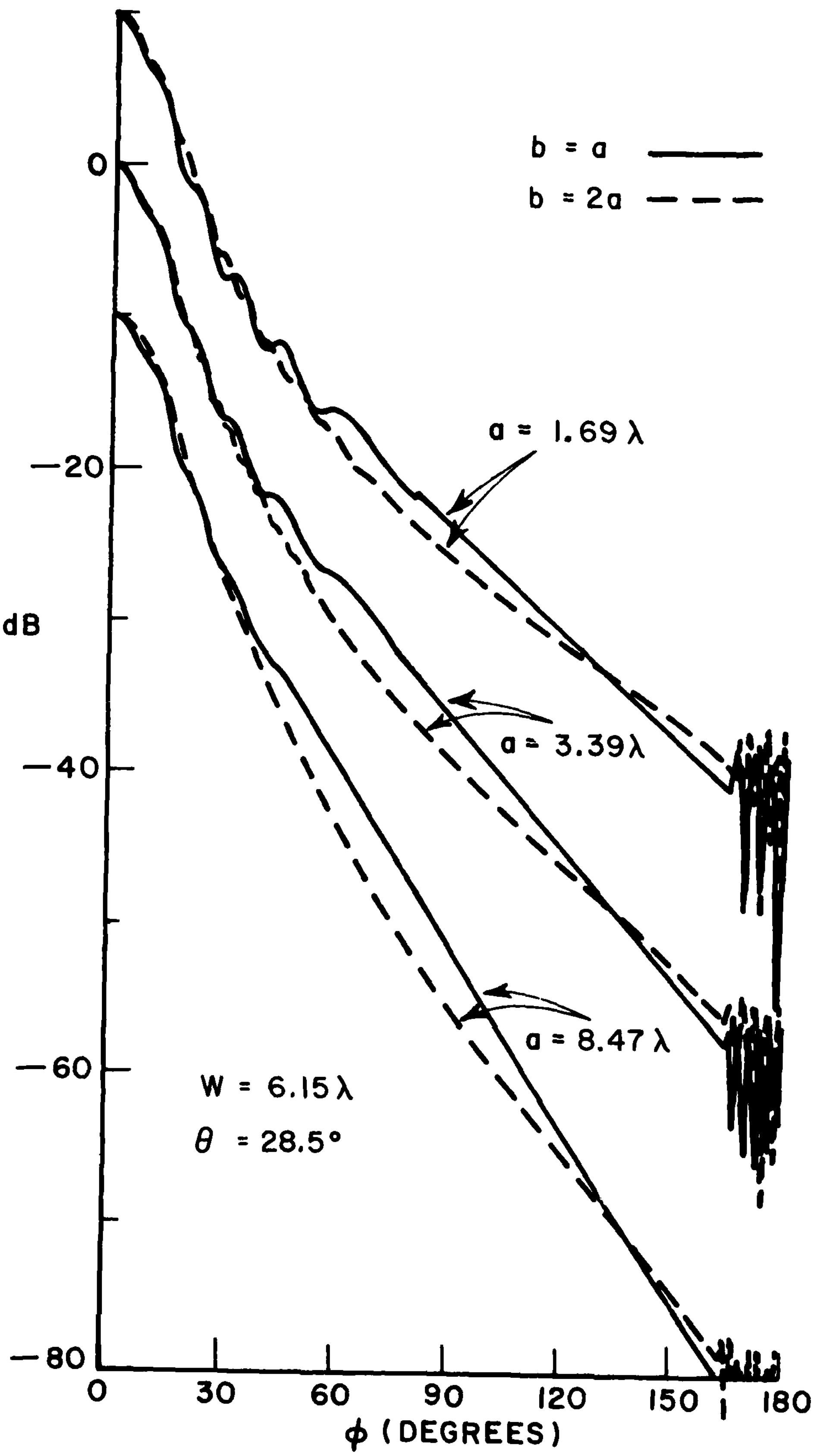


Fig 15. E-plane patterns for elliptic cylinder "aperture-matched" horns.

both fit within the same volume. Note that the corrugated horn and associated data are taken from Ref. [4]. Various E-plane patterns are shown in Fig. 16, which illustrate that the "aperture-matched" horn has a much smoother pattern and lower back lobe than the conventional horn; yet, it does not provide the same reduction in the wide side lobes as compared with the corrugated horn. This implies that one would have to increase the overall horn size in order to achieve nearly the same E-plane pattern. Provided the aperture match and corrugated horn modifications are only applied to the E-plane edges, the H-plane patterns of the "aperture-matched" and corrugated horns are virtually the same as that for a conventional horn except for a greatly reduced back lobe level. Using the same horns, the back lobe level as a function of frequency is shown in Fig. 17. At the lower end of the frequency band the corrugated horn has a lower back lobe; whereas, the "aperture-matched" horn has superior performance at the high end. Both the "aperture-matched" and corrugated horns are significantly better than the conventional horn. The beamwidth for the various horns is illustrated in Fig. 18. As one might expect the beam width for the conventional horn is smallest in that it has a uniform distribution across the complete aperture plane; whereas, the corrugated and "aperture-matched" horns have tapered distributions.

What about the frequency behavior of the "aperture-matched" horn? In order to answer this question, let us examine the frequency dependence of the diffraction coefficient alone as shown in Figs. 9-12 assuming that the source and receiver positions and cylinder radius remain fixed. As observed previously, the planar/curved surface diffraction coefficient magnitude is much smaller than that for the half plane provided the cylinder radius is greater than a half wavelength. So one might expect that the "aperture-matched" horn has much better frequency performance than a dual-mode, corrugated, or even conventional horns. This statement is justified based on the E-plane horn patterns shown in Fig. 19.

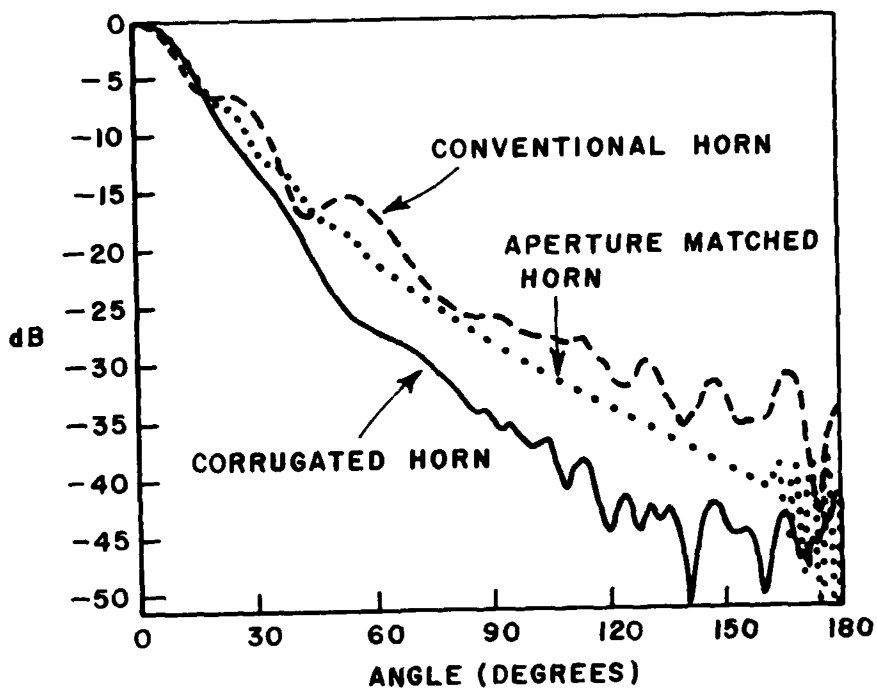


Fig. 16. Various E-plane horn patterns. The "aperture-matched" horn pattern is calculated and the others are measured.

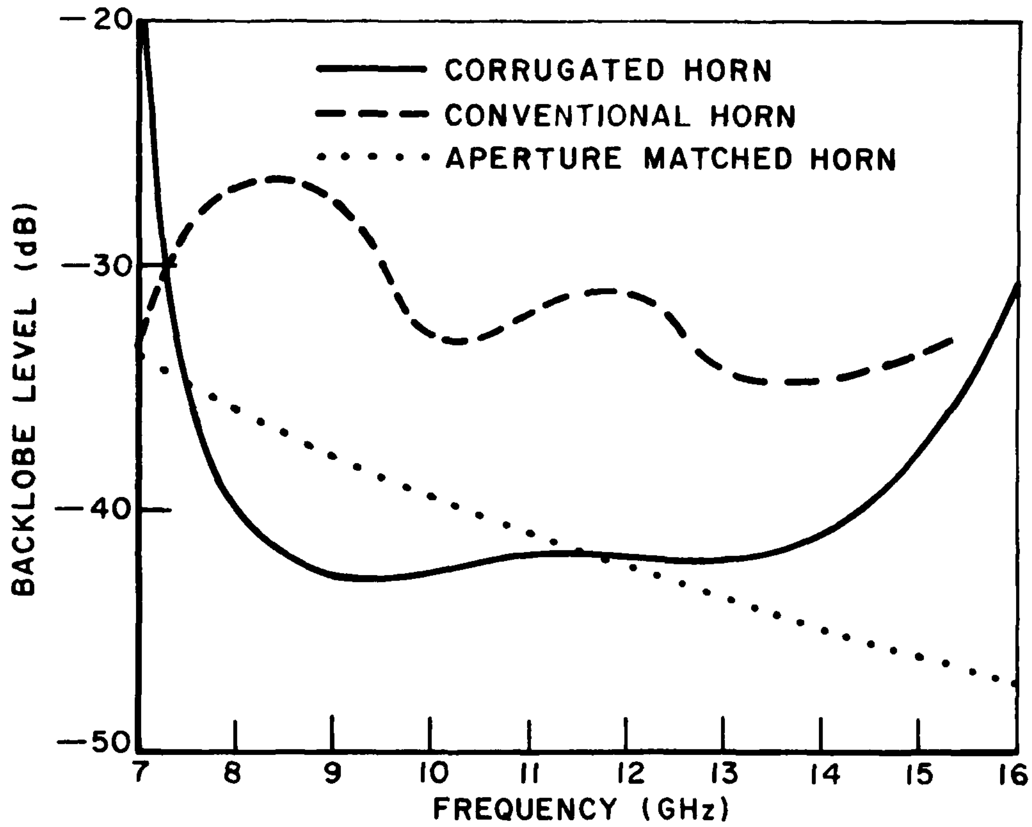


Fig. 17. Back lobe level as a function of frequency. The "aperture-matched" horn data is calculated and the others are measured.

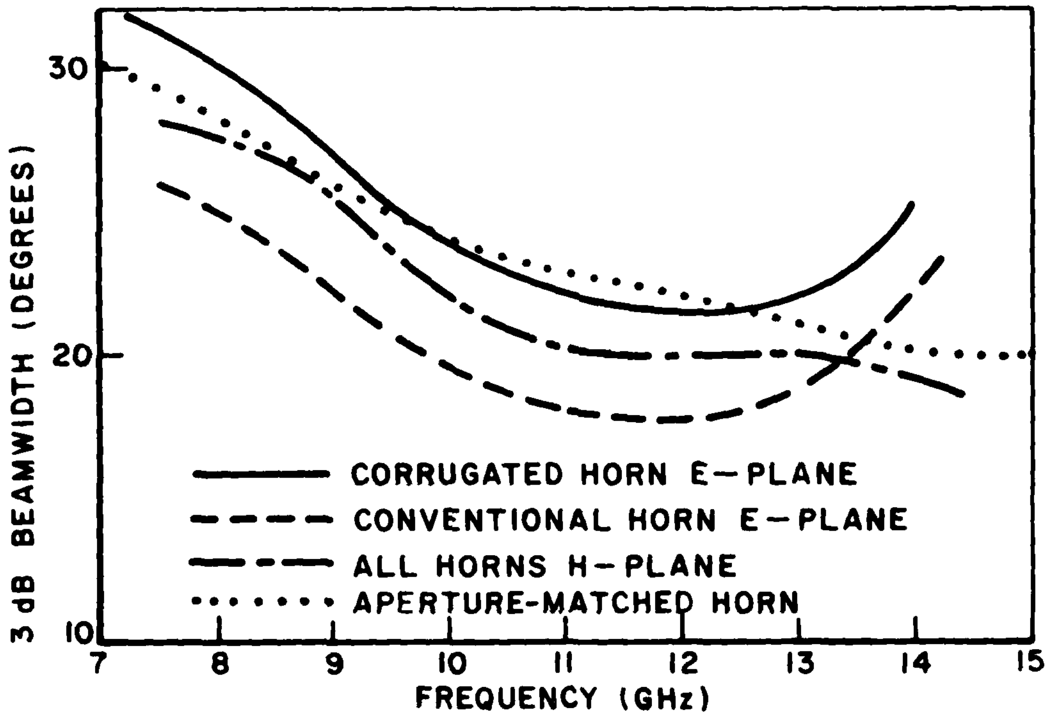


Fig. 18. Three decibel beam width versus frequency. The "aperture matched" horn data is calculated and the others are measured.

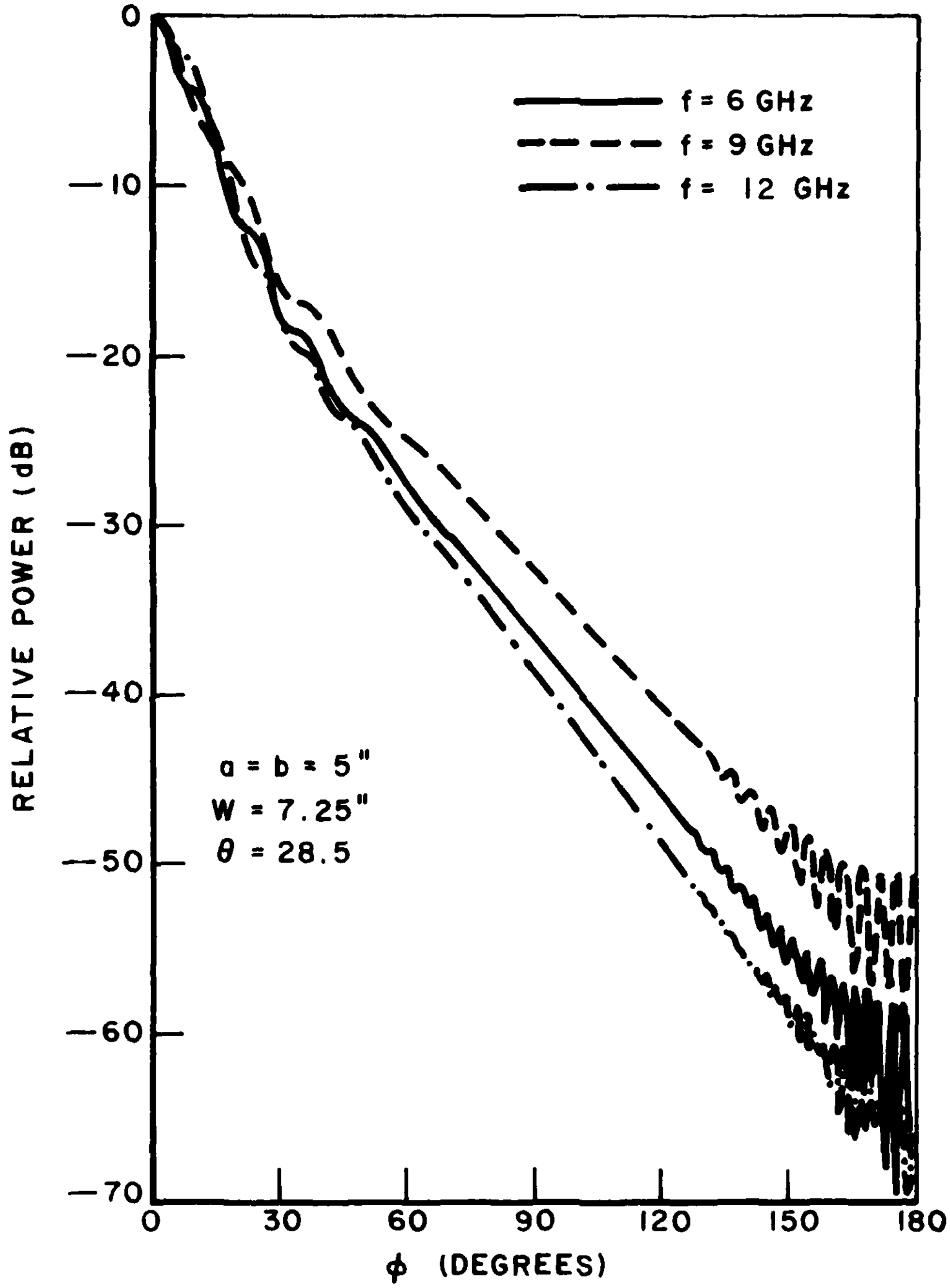


Fig. 19. Calculated E-plane patterns of "aperture matched" horn versus frequency.

The physical limitations of the "aperture-matched" horn remains a concern in that the curved surfaces may significantly increase the outside dimensions of the horn. To partially solve this size and weight problem, it's suggested that quadrant elliptic sections be attached to the aperture edges such as illustrated in Fig. 20. Using such structures the aperture width is not greatly increased, and yet one obtains superior E-plane patterns.

If one wishes very low side lobes, he might consider using curved surface sections on a normal corrugated horn. If even lower side lobes are desired, one could even corrugate the curved surface sections. In any event, if one corrugates the horn or not, it is apparent that the coupling between horns which are not facing each other will be reduced using the "aperture-matched" horn. In fact, it provides an excellent modification for flush mounted antennas where coupling is a problem.

III. IMPEDANCE PERFORMANCE

As presented in the previous section the aperture reflection back into the horn is greatly reduced using the "aperture-matched" horn. In that the aperture reflection is only one of two significant terms making up the normal horn impedance, the throat reflection, now, remains as the dominant contributor. Using the procedure suggested by Terzuoli, et. al [8], one can also reduce the throat reflection by adding a throat matching section as shown in Fig. 17. Note that the curved section in the throat forms a smooth transition between the waveguide and horn walls. Such a throat section is available on a NARDA* standard gain horn. Simply using the NARDA horn, its impedance was measured across X-band, and the results are shown in Fig. 22. In that the throat reflection is negligible compared

---

Horn manufactured by:

Narda Microwave Corporation
Plainview, New York

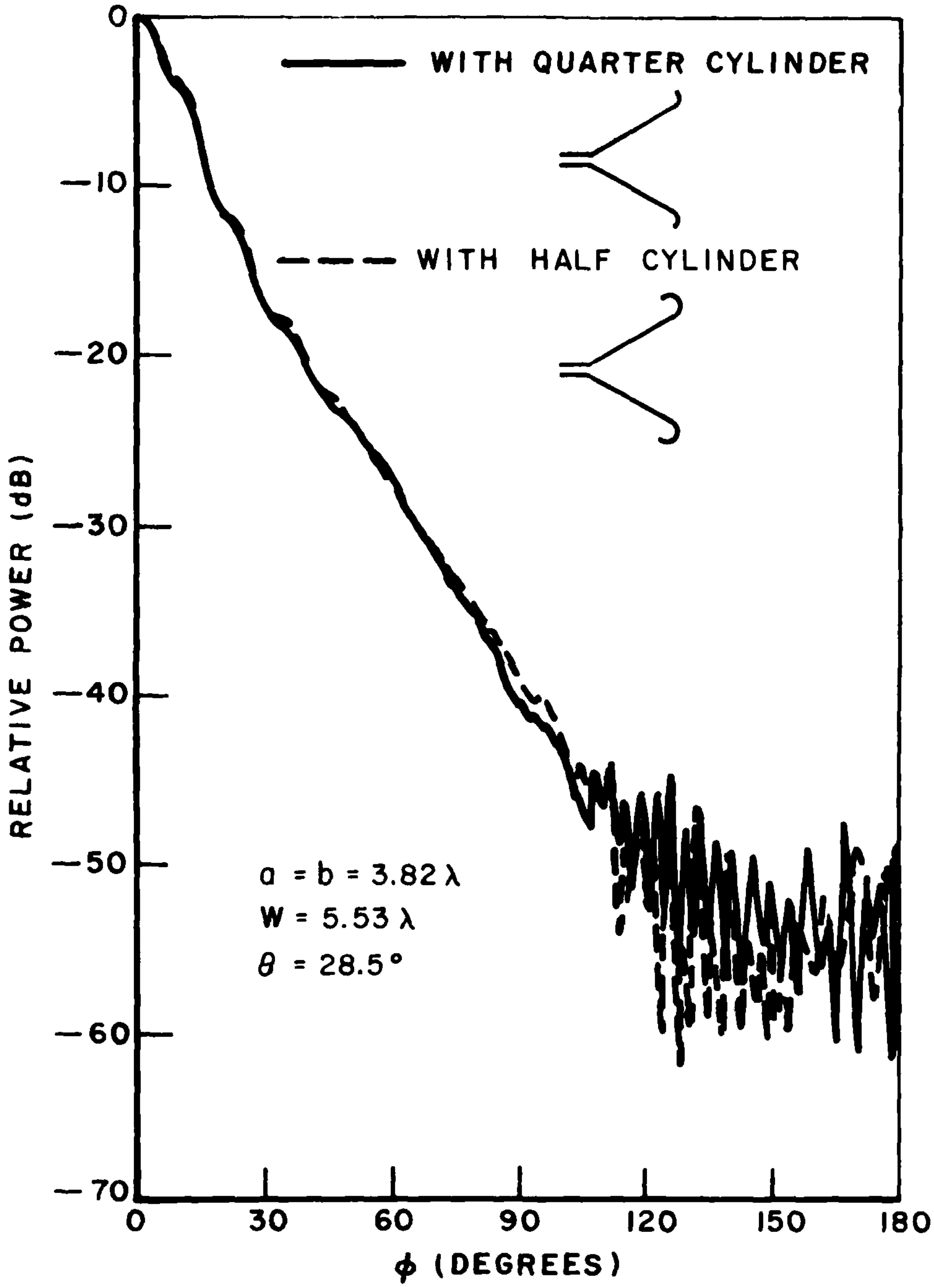


Fig. 20. Measured E-plane patterns of "aperture-matched" horn.

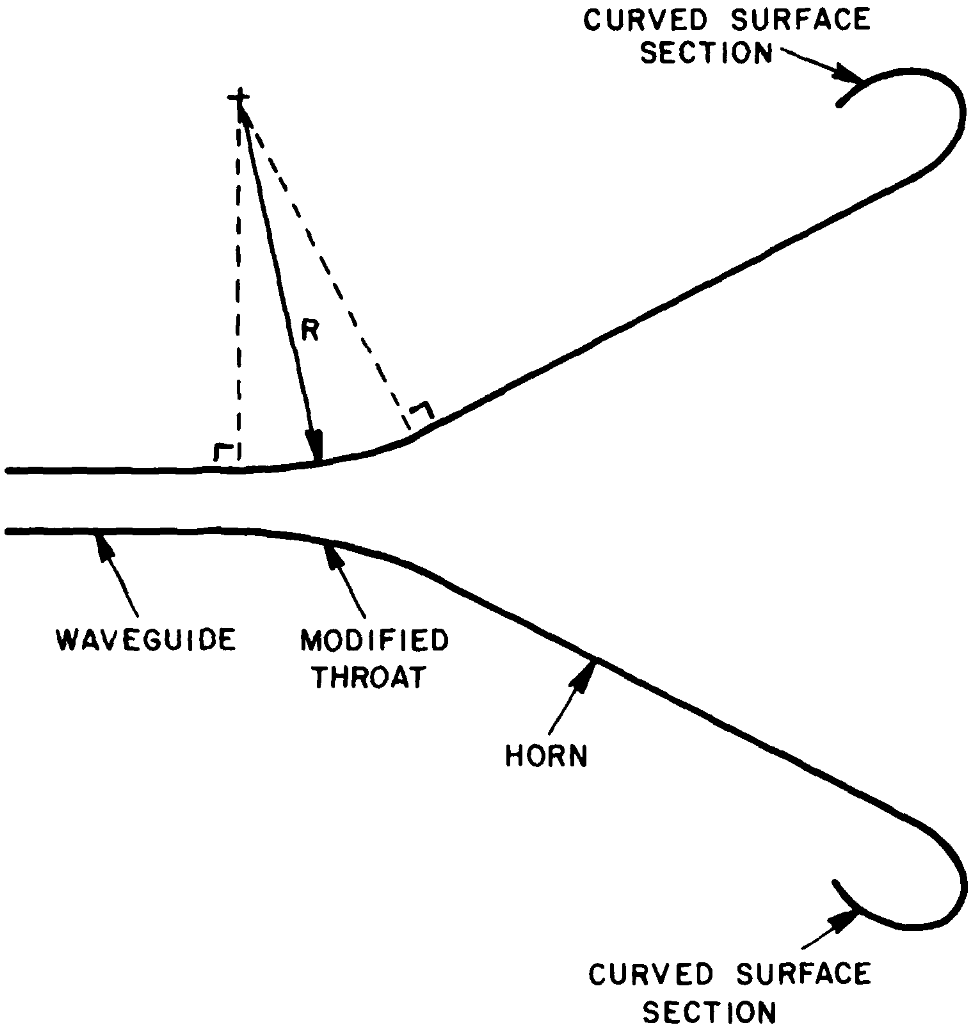


Fig. 21. "Aperture-matched" horn with a modified throat section.

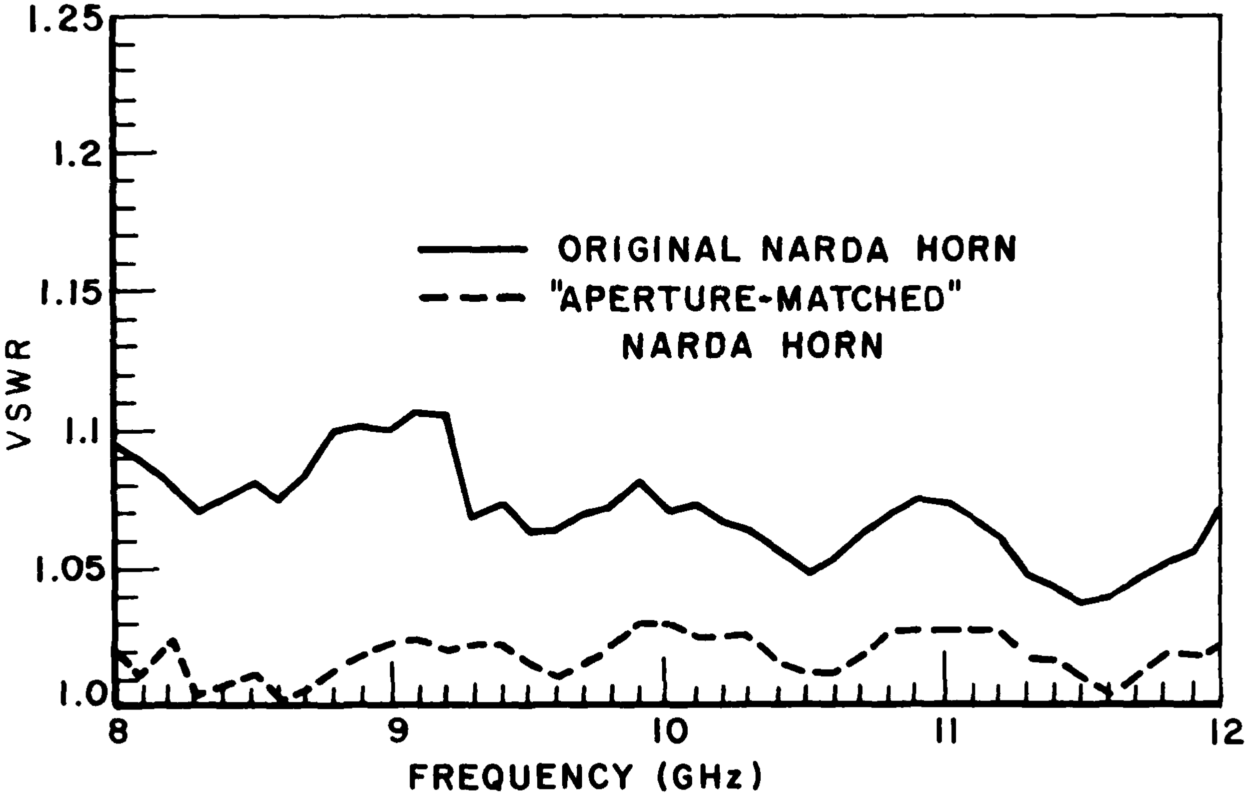


Fig. 22. Measured VSWR for various horns.

to the aperture reflection, one obtains a relatively small VSWR across the frequency band. On the same figure, the horn impedance is shown with small circular cylinder sections added to the NARDA horn. It is very apparent from these results that the "aperture-matched" horn with a modified throat has superior impedance performance compared to either a conventional horn or one with a modified throat section. In addition, it is felt that an even greater bandwidth than shown in Fig. 22 can be achieved using a ridged waveguide to feed the horn.

IV. CONCLUSIONS

The basic electromagnetic characteristics of a new horn design have been presented in this paper. It is known as an "aperture matched" horn in that curved surfaces are attached to the aperture edges in order to form a matching section between the horn modes and free space radiation. Although the curved surface sections treated in this paper are portions of elliptic cylinders as shown in Fig. 13, they can be arbitrary smooth, convex shapes provided that they are attached in such a way to form a smooth junction at the original aperture edges. Such a horn provides superior E-plane patterns, input impedance, and frequency characteristics as compared with a conventional horn (i.e. the same horn without the aperture matching sections). The size and weight of the "aperture-matched" horn are somewhat increased over those of a conventional horn. However, this increase can be kept to a minimum if quadrant curved sections are used as shown in Fig. 20. Due to the simplicity of the modification for such a horn, the additional construction costs should be minimal. Further, if one uses elliptic cylinder sections, then the "aperture-matched" horn can be analyzed, as done here, using the numerical method suggested by Chuang and Burnside [7] such that the design costs should not exceed those of a conventional horn.

A very beneficial aspect of the "aperture-matched" concept is that it can be used as a retrofit to improve the electromagnetic performance of virtually any horn.

REFERENCES

[1] "Electromagnetic Horn Antennas," IEEE Press Monograph, Edited by A.W. Love, 1976.

[2] Schelkunoff, S.A. and H.T. Friis, "Antennas Theory and Practice John Wiley & Sons, Inc., Appendix VI, 1952.

[3] Potter, P.D., "A New Antenna with Suppressed Sidelobes and Equal Beamwidths," Microwave Journal, June 1965.

[4] Lawrie, R.E. and Peters, L., Jr., "Modifications for Horn Antennas," for Law Sidelobe Levels," IEEE Trans. on Ant. and Prop., September 1966.

[5] Russo, P.M., Rudduck, R.C. and Peters, L., Jr., "A Method for Computing E-Plane Patterns of Horn Antennas," IEEE Trans. on Ant. and Prop., March 1965.

[6] Kouyoumjian, R.G. and Pathak, P.H., "A Uniform Geometrical Theory of Diffraction for an Edge in a Perfectly Conducting Surface," Proc. IEEE, Vol. 62, pp. 1448-1461, November 1974.

[7] Chuang, C.W. and Burnside, W.D., "A Diffraction Coefficient for a Cylindrically Truncated Planar Surface," to be published in IEEE Trans. on Ant. and Prop.

[8] Terzuoli, A.J., Richmond, J.H. and Peters, L., Jr., "The VSWR of E-Plane Dihedral Horns," IEEE Trans. on Ant. and Prop., March 1978.